TESTING OF FLUORESCENT DC LAMPS FOR SHSs

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FIGURES

Figure 1. Woman asking how to replace the tubes in the Bolivian High Plateau.

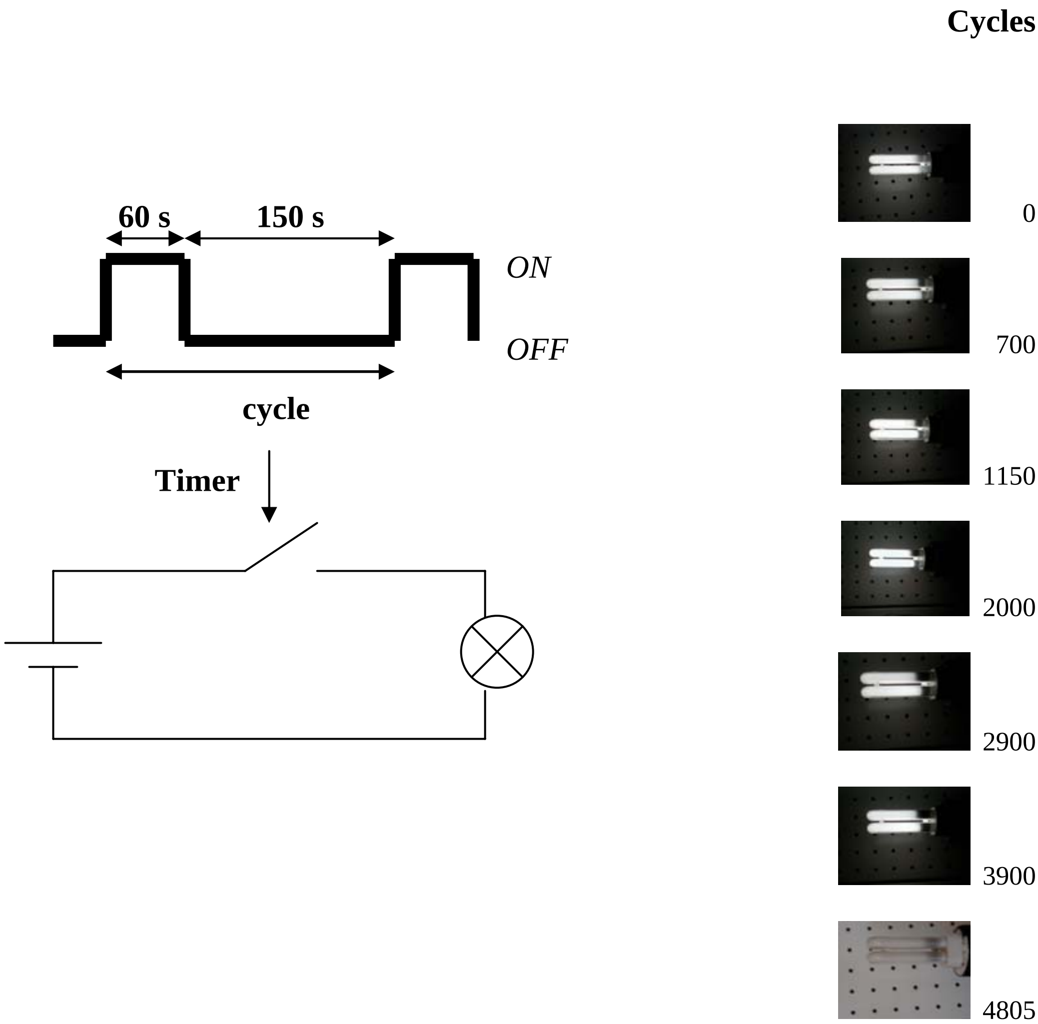

Figure 2. “Cycler” for testing the lamp resistance to ignitions.

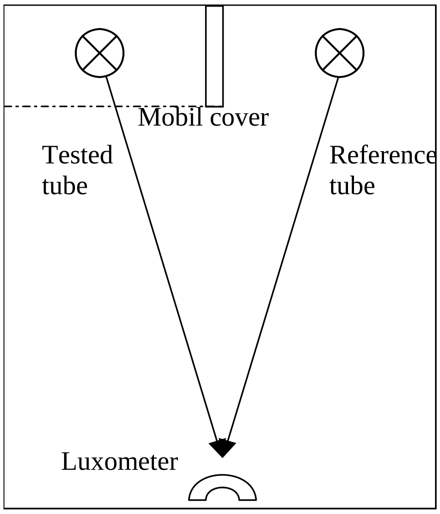

Figure 3. Black box for measuring lamp luminosity.

CYCLES
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

Figure 4. Cycling test results for five different lamps.

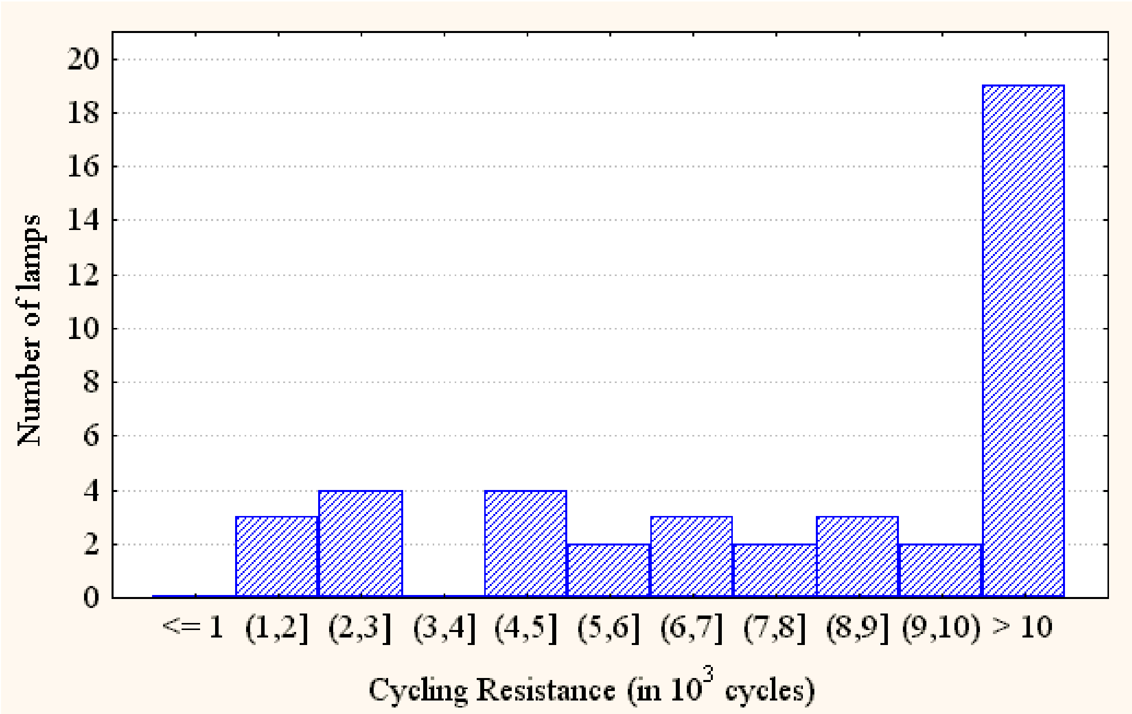

Figure 5. Cycling resistance of the tested lamps.

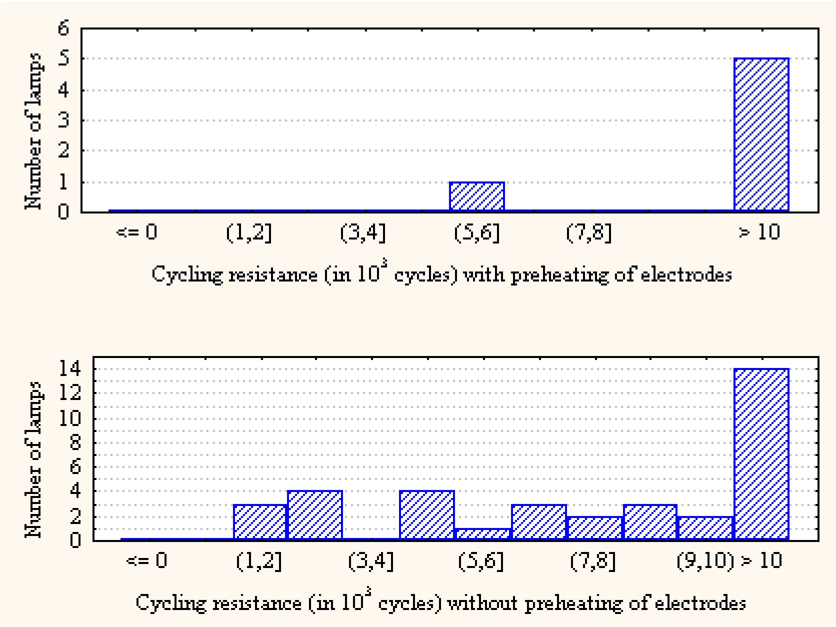

Figure 6. Different cycling lifetime distribution of lamps having and not preheating of electrodes.

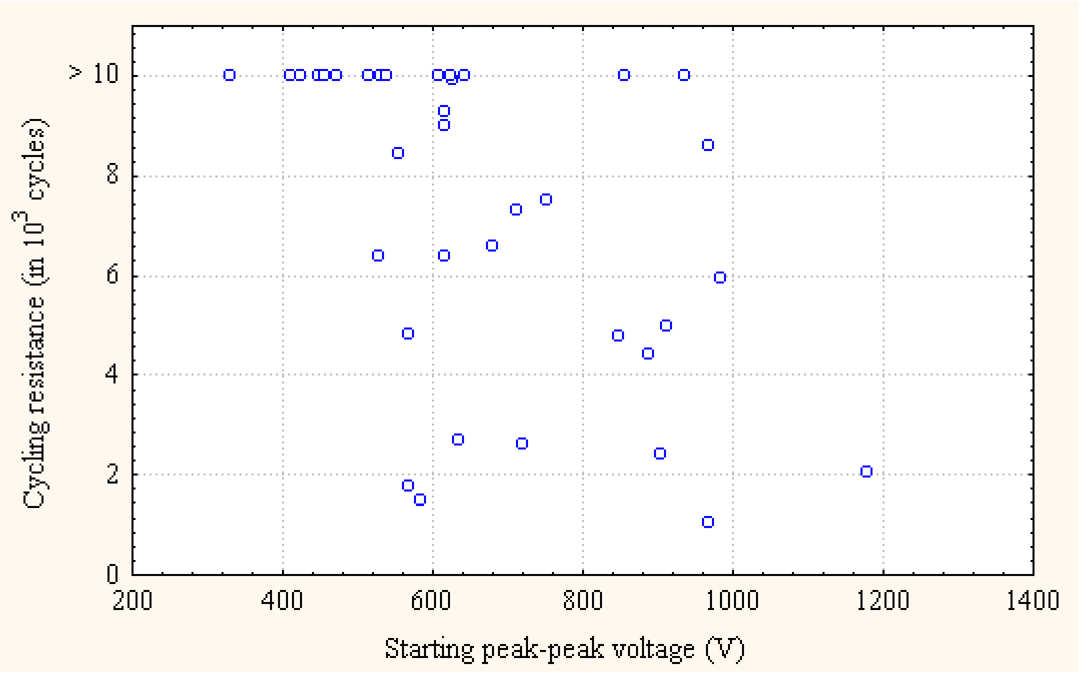

Figure 7. Relationship between starting voltage and cycling resistance of the lamps.

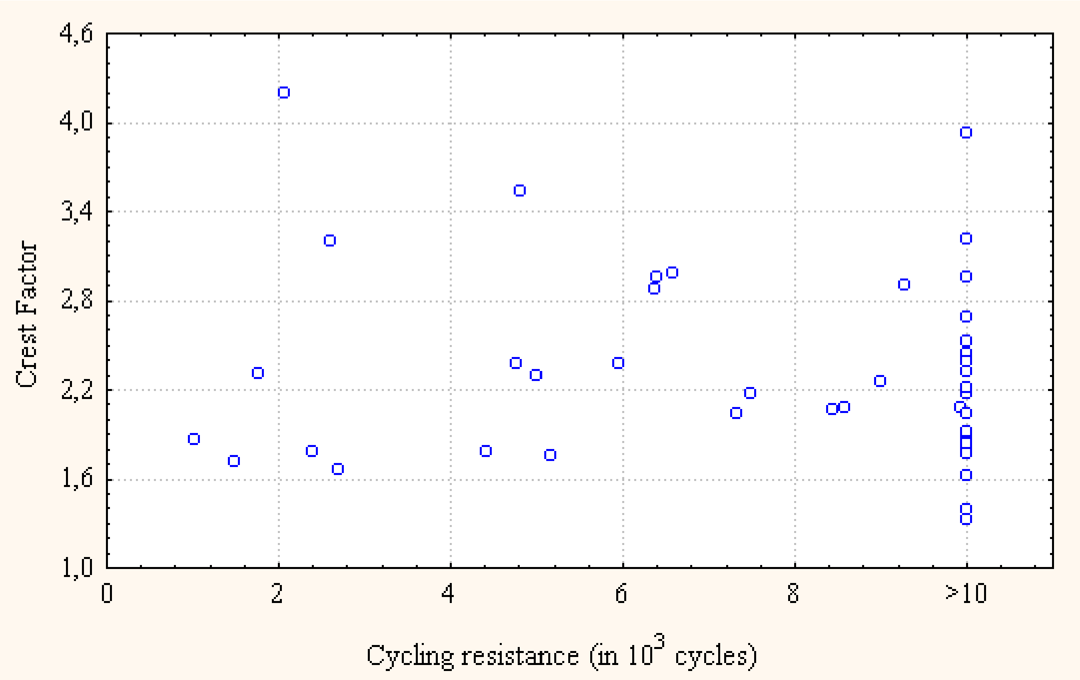

Figure 8. Relationship between crest factor and cycling resistance of the lamps.

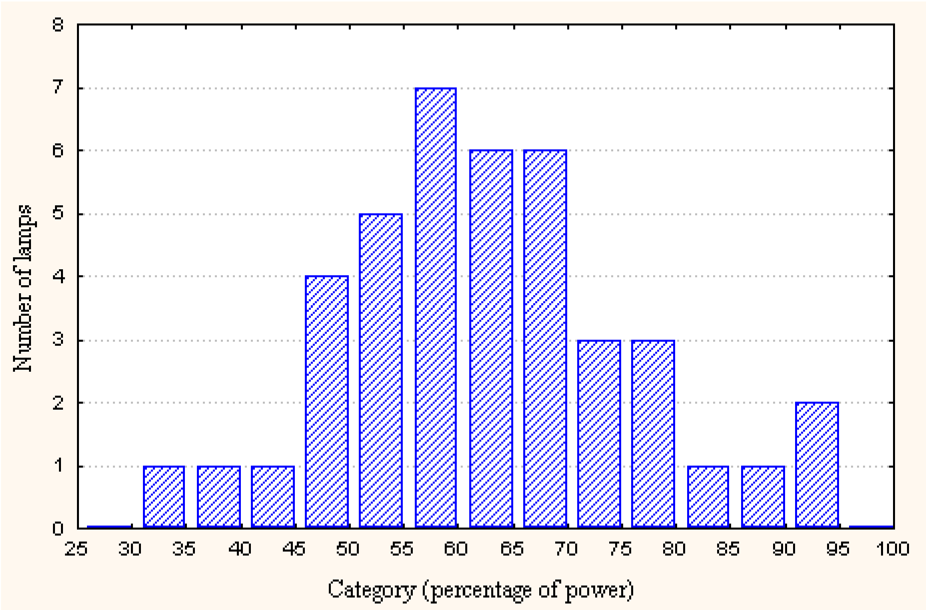

Figure 9. Percentage of the tube nominal power delivered to the tube.

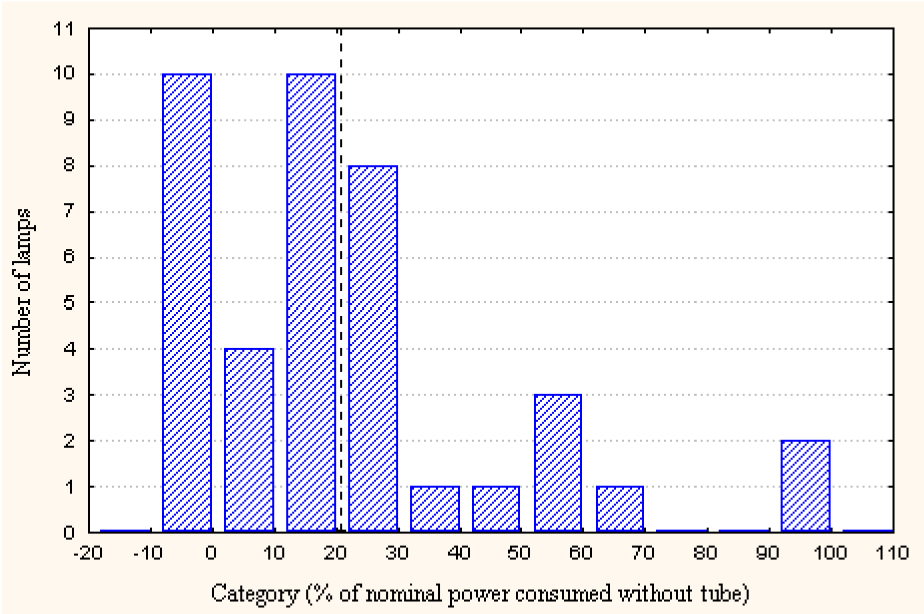

Figure 10. Percencentage of the nominal power consumed by the lamp when working without tube. The dotted line represents the allowed limit by the Universal Technical Standard.

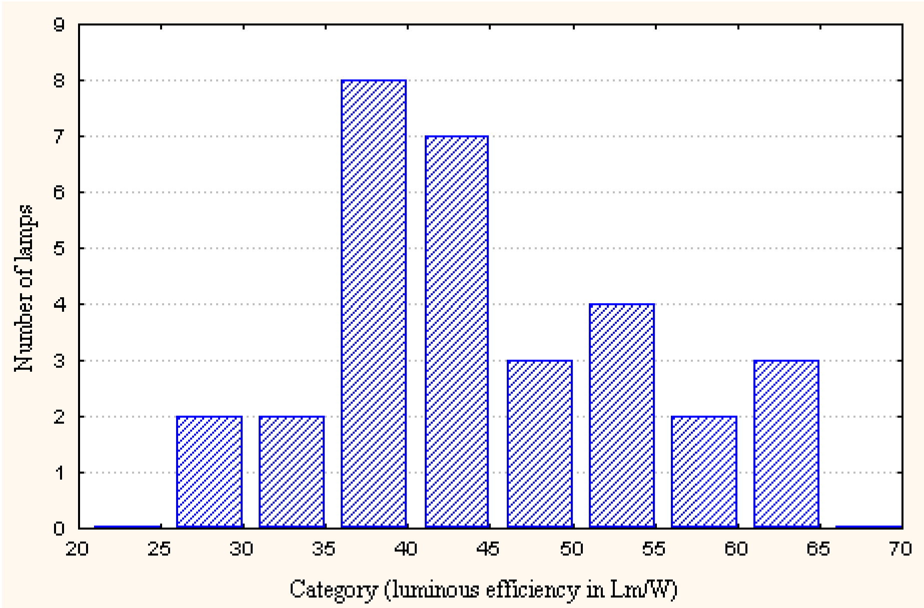

Figure 11. Luminous efficiency results in lumens per watt of DC power at the lamp input.

LIST OF FIGURE LEGENDS

TABLES

TESTS and REQUIRED DAYS		
Visual inspection ½ day		
*Lamp degradation: 100 hours of continuous o*peration 4 days		
Electric test 1 day	*Cycling test* < 25 days	*Luminous flux test* 1 day
Protection test 1 day		*Low temperature test* 1 day
		High temperature test 1 day
Reporting 1 day		
***Total time*: 30 days**		

Table 1. Sequence of the different steps of quality test procedures and their corresponding required times.

Country	**Quantity**	***Nominal Power (W)***	**Quantity**	***Type of lamp***	**Quantity**
Argentina	7	*7*	3	*PL*	7
Brazil	6	*8*	7	*Tube*	35
Spain	13	*10*	5		
United Kingdom	11	*13*	5		
Morocco	2	*15*	7		
Indonesia	1	*18*	4		
Bolivia	2	*20*	9		
		30	1		
		36	1		
TOTAL	42	TOTAL	42	TOTAL	42

Table 2. Main characteristics of the lamps of the market sample.

Protection against:	Test result (%)	
	Success	Failure
Short-circuit of ballast outputs	56	44
Reverse polarisation	95	5
Destruction when working without tube	95	5
Electrical connection with lighting fixture	65	35
EMC	12	88

Table 3. Protection test result for the lamps of the market sample.

LIST OF TABLE LEGENDS

Summary

After the elaboration of the so-called "Universal Technical Standard for Solar Home Systems", procedures to test the adherence of SHS fluorescent lamps to it have been developed. The definition of these laboratory testing procedures is a required step of any lamp quality assurance procedure. Particular attention has been paid to test simplicity and to instrumentation affordability, in order to make easy the local application of the testing procedures, for example by the organisations which carry out electrification programmes.This set of test procedures has been applied to a representative collection of 42 lamps from many different countries and directly acquired in the current PV Rural Electrification market. Tests apply to lamp resistance to normal operation conditions, lamp resistance to extreme operation conditions, lamps resistance to abnormal operation conditions, and lamp luminosity. Results are discussed and some recommendations for the up-date of the concerned standard are given. The selected technical standard together with the proposed testing procedures form the basis of a complete quality assurance tool that can be locally applied in common electricity laboratories. Full testing of a lamp requires less than one month, what is very reasonable on the frame of quality assurance programmes.

1. Introduction

Roughly, two billion people, living in the poorest villages of the so-called developing world, can not access to the conventional electricity grid. For them, lighting is restricted to candle and kerosene lamps which provide poor level of lighting, usually produces smoke and smell, and represents a constant fire hazard. Electric lighting encompasses significant advantages when comparing with this situation. Only as an example, the luminous flux of a kerosene wick lamp is typically about 40 lumens, while the luminous flux of an 8-watt fluorescent lamp, easily reaches 400 lumens, i.e., ten times more. This is why the development of the current electricity grids is historically related with the incandescent lamp, invented by Thomas Edison in 1878, and also why lighting is presently the biggest application of photovoltaics, in terms of the number of installations. Market indicators lead to estimate that about 1.3 million of Solar Home Systems, SHS, for lighting, radio and television are currently in operation.

For efficiency reasons, fluorescent lamps normally form the basis for lighting in SHS. The ballast of a fluorescent lamp is essentially an oscillator that ideally has to assure high energy and luminous efficiency and a long lifetime for tubes. However, notices from the field suggest that realities are often far from such ideal, and that performance and reliability of fluorescent lamps in SHS use to be well below the expectations:

- Van der Plas says in reference to the Kenyan experience[1]: *"Roughly 1/3 of all fluorescent lamps, mostly the locally-made units, are blackening (this is caused by under-voltage supply with poor quality inverters)"*.
- Barbosa about an experience in the Northeast of Brazil[2]: *"Comparative results after one (1995) and three years of operation (1997): ... Lamps: very frequently, lamps are operating in bad conditions, with one or both of its edges darkened. In 1995, 5% of the lamps were burnt. This fraction increased to 22.3% in 1997"*.

- Hammami about the Tunisian programme[3]: "*Technical evaluation:..... The ballast performance for florescent tubes is very variable depending of the model. The worst ones lead to a very short duration of tubes.... The implemented PV projects have allowed to know better the essential technical characteristics to be demanded to ballast manufacturers*".
- Pedro about Argentinean programme in Neuquén[4]: "*Percentage of tubes replaced after two years of operation: once, 80.6%; twice: 16.7%; more: 2.7%*".
- Wamukonya says in reference to the Namibian experience and the interference on radios and TVs caused by the luminaries[5]: "*Overall, the share of households relying on dry cell batteries in the solar electrified households is quite high, 67%, mainly because their radios are incompatible with solar-system. 86% of the 35% households who owned a TV before electrification used lead-acid batteries to power it and majority of these are still using them because the TV are incompatible with the system or the power available is inadequate*".
- Munguía del Río about the PRONASOL programme in Hidalgo State, where SHSs with four-lamps were installed[6]: "*The number of luminaries still working in each system is as follows: four luminaries: in 1% of the systems; three luminaries: 40%; two luminaries: 22%; one luminary: 13%; and none of the luminaries working in 24% of the SHSs*".

This disappointing reality and the consequent need for quality assurance are certainly widely recognised, and have motivated several international actions towards the promotion of standardisation and certification practices, in the same line of those already existing for PV modules. Initiatives have been taken by different agencies: rural electrification promoters (national governments, World Bank) and international certification bodies (IEC, PV-GAP). An extended review of these activities has been recently performed by the GTZ[7].

However, despite these efforts, internationally recognised certification procedures are still not effectively available for the BOS components of SHS –including lamps-, so that, immediate projects trying to implement some quality assurance procedure should essentially be self-reliant. Just to help on this is being a main IES commitment from 1997. It should be stressed that self-reliance implies that the pertinent test procedures could be directly applied by laboratories within reach of the organisations that carry out electrification programmes. Such laboratories are usually equipped with only standard electrical instrumentation and are not necessarily accredited by international certification bodies (ISO 25 or similar). This way, self-reliance alternatives can not adhere to international standards. However, this does not mean neither they are in contradiction, nor they are exclusive. In this sense, we should clarify that our present work is being motivated by the persistence of technical problems that, ay present, remain out of the reach of such international standards. But we certainly will applaud the arrival of other alternatives based on them, if able to solve the today existing problems and, thus, turning our alternative useless.

A first relevant step in this IES commitment was the elaboration of the "Universal Technical Standard for Solar Home Systems" published by the European Commission in the framework of a Thermie B project[8], where outstanding PV experts working in rural electrification programmes collaborated, and that has been widely diffused in scientific ambiences[9,10,11], being distributed in English, French and Spanish editions. The elaboration of this standard has paid special attention to learn from field experience, and to include flexibility features, allowing it to be adapted to the particular conditions of each country. In order to this, the norms presented in the standard have been classified into three categories: Compulsory, Recommended and Suggested. Now, the definition of laboratory testing procedures, leading to determine the adherence of prototypes to the concrete specifications of a selected standard, is a required step of any quality assurance procedure. This paper deals just with the testing of fluorescent lamps, following the Universal Technical Standard for Solar Home Systems. Testing procedures have been defined, and a wide testing campaign, on a representative collection of more than 40 lamps acquired in the current SHS market, has been carried-out. Results are discussed and some recommendations for the up-date of the concerned standard are given.

2. Lamp performance, standards and testing.

Figure 1 comes from a real project[12] and shows a PV user worried by replacement possibilities of failed fluorescent lamps. Spare market availability is out of the direct scope of this paper, but the figure is still useful here, because it exemplifies the great importance of reliability in rural contexts. To insist on reliability concerns can appear as an obviousness; but it is not when considering that, despite failures persist as an uncomfortable part of realities in the field, as the above described literature indicates, lamps reliability is being scarcely addressed in current PV rural electrification market practises.

Figure 1. Woman asking how to replace the tubes in the Bolivian High Plateau.

Roughly, the reliability of particular equipment depends on its resistance to normal and abnormal operation conditions. Concerning the last, a look on standards and procurement documents from SHSs programmes[13,14,15,16,17,18,19,20] reveals that only protection against reverse polarity is generally required, while other frequent abnormal conditions as, for example, operation without the tube or with a tube that does not ignite are seldom considered. On the other hand, resistance to normal operation, i.e. hours of lifetime and number of ignitions, use to be indirectly considered through some electrical parameters, namely the crest factor of the voltage waveform applied to the tube (from the ballast) and the symmetry of the waveform of the current through the tube, which are supposed to strongly influence the lamp durability[17,21,22,23,24]. However, as far as we know, the relationship between such parameters and the real durability of the lamp has never been properly clarified. Not surprisingly, significant differences are found among different technical recommendations. For example, crest factor values as high as 3 are allowed in Ref.[25], while they are limited to 2 in Ref.[16] and to 1.7 in Ref.[21]. And this rather weak situation regarding technical specification is being worsened by the lack of effective testing in current procurement procedures. Available literature[26,27] suggests that, despite some valuable attempts[14,28,25], independent testing is far from being an extended practise today. Based on our own experience, we estimate that not more than 10% of all the fluorescent lamp types found in the present PV rural electrification market, have been sometimes submitted to an independent test. Rather similar comments apply to luminosity and efficiency aspects. The value of 35 lumens/W is often referred in procurement documents[14,15,16] but seldom effectively tested. And the same is true when personal safety and radio-interference are concerned.

To summarise, fluorescent lamp technical performance is today essentially entrusted to the goodwill and skill of the manufactures, and that is paving the way for the coexistence of large quality disparities, leading sometimes to unacceptable failure rates. And this situation is being sustained, in part, by the extended idea that testing is mainly a matter of few laboratories, equipped with rather sophisticated means (integrating spheres for luminosity measurement, etc.). Such idea is not a good match neither for the decentralised nature of the PVRE market, nor for the current existence of small-scale lamp local production, which should be preserved. We believe that, in general, SHS technical quality assurance is more a matter of will that one of technical sophistication, and that rather simple and local testing can be very effective today.

Looking for this goal, we are systematically testing SHS fluorescent lamps from 1997. As mentioned at the introduction, the selected reference base has been the “Universal Technical Standard for Solar Home Systems”[8]. It can be observed that the matter of the lamp resistance to normal operation is not directly addressed at this standard, but only indirectly through the above mentioned related electrical parameters. To further study this relevant aspect we decided also to directly test such resistance. In pursuit of possible local implementation, we have paid particular attention to simplicity and affordability when selecting the required instrumentation.

The specific instrumentation we use is restricted to two “home-made” machines: a “cycler” for testing the resistance to ignitions, and a “black box” for testing luminosity.

The first is composed of a programmable timer acting over a relay, which allow for periodical cycling, and a counter and a camera to photograph, approximately one picture per 500 cycles, the evolution of the lamp (see figure 2). The second is composed by a black box in which the tested lamp and another previously calibrated one are placed together, and in the same relative position to a standard photometer (see figure 3). When moving the sensor along an axis normal to the sheet, the measured illumination, in luxes, presents a maximum, F_M, which is obviously related with the luminous flux of the lamp, F, in lumens. For linear tubes whose diameter is several times shorter than the distance between the lamps and the sensor, it can be shown[29] that such relationship can be expressed as:

$$F = F_M . K \qquad (1)$$

where K depends on the length of the tube, L, and on the distance between the tube and the sensor, d. In our case, d = 1.4 m, and K can be approximated by the expression

$$K = 19.4165 - 0.00252.L + 0.0001831.L^2 \qquad (2)$$

For compact lamps a similar reasoning can be done, reaching expressions of K that depends of the compact lamp type.

Figure 2. “Cycler” for testing the lamp resistance to ignitions.

Figure 3. Black box for measuring lamp luminosity.

The use of a previously calibrated lamp with a similar tube that the tested one allows compensating the possible errors associated to lamp temperature variability and non-linearity of the sensor effects. The accuracy attainable with such machine has been analysed by testing seven different lamps and comparing the results with the ones obtained in integrating spheres available at the CIEMAT and at the Institute of Electrotechnics and Energy of Sao Paulo University. It is worth to mention that differences are always below 4% when the calibrated and the tested lamp have tubes of the same model, which largely suffices for quality assurance purposes. Note that the price of an integrator sphere is about 80000$, while the price of the materials of our home made machine has been less than 300$.

This instrumentation is completed with a standard domestic refrigerator and an oven, to test the lamp behaviour in low (-15ºC and 0ºC) and high temperatures (50ºC), respectively, and a standard radio-receiver to observe the possible interferences. Finally, we use an oscilloscope and some standard multimeters. Table 1 describes the implemented test sequence and the corresponding required times.

Table 1. Sequence of the different steps of quality test procedures and their corresponding required times.

The correct implementation of the test procedures requires the following precautions:

1- The tube used in the lamp has a great influence in the test results[30,31]. Therefore, the tests must be carried out with a complete lamp, composed of ballast and tube, the same ones that are going to be installed in the rural electrification programme.

2- Five lamp units are required to perform all the tests[32,33]: three for the cycling test, one for the electric tests, and one for the luminosity and extreme condition tests.

3- All the tests must be done at the DC nominal voltage (usually, 12 V).

4- Lamps need some time of operation to reach their stable characteristics. Therefore, a previous 100 hours of continuous operation is required before the beginning of the test sequence[34,24].

5- Lamp lifetime is affected by the sort of the ON-OFF cycle[35]. In the case of fluorescent lamps, the cycling test must establish a cycle that allows the tube to get cold before starting again. A variety of ON-OFF cycles can be found in the literature[32,28,36,24], but only some of them fulfil the need of being also short enough to carry out the test in a reasonable time. The selected procedure consists of cycle of 60 seconds ON and 150 seconds OFF, cycle used by some European laboratories[31,36] and by some lamp manufacturers in their internal quality procedures.

6- The luminous test must be carried out without reflector by covering it with a black and matt fabric. Furthermore, the lamp should be allowed to stabilize for about 2 hours before a lux measurement is conducted.

3. RESULTS AND DISCUSSION

Table 2 summarises the main characteristics of 42 lamps we have tested up to now. We think this sample is large and wide enough to be considered as representative of the current state of the art.

Table 2. Main characteristics of the lamps of the market sample.

For presentation purposes, results are classified into four different categories:

3.1 Resistance to normal operation conditions

That means resistance to, both, continuous operation and ignition. However, lifetime in continuous operation has been larger than 14000 hours for all the tested lamps. In fact, many of the lamps still remain on this test when writing this paper, because they are in proper condition after more than two years in continuous operation. When considering that the typical use of SHS lamps is characterised by a relatively high ratio between the number of ignitions and the hours of operation[37], such a result leads us to believe that the factor limiting the lifetime in real SHS is essentially the cycling resistance. Hence, in what follows, we will focus just on it.

Figure 4 presents the behaviour of 5 different lamps, just to exemplify the large disparities offered by the current market. More in detail, figure 5 summarises all the test results. A first approximation to the state of the art of the present market is obtained when noting that more than 7% of the lamps died before 2000 cycles, 26% died before 5000 cycles and that 45% resisted more than 10000 cycles. This fact leads us to provisionally name “poor” lamps those that have not reached 2000 cycles, and “good” lamps those that have passed 10000 cycles.

Figure 4. Cycling test results for five different lamps.

Figure 5. Cycling resistance of the tested lamps.

Looking for possible quickly indicators of the lamp cycling resistance, it is worth to analyse its relationship with other lamp electrical features of easy and immediate verification: preheating of electrodes, starting peak voltage, crest factor of the voltage, current waveform, and the ratio between real and rated power. The last is scarcely referred at lamps specialised literature[21,31,38,39], but we decided to also consider it because we have observed that, very often, the real powers consumed by the ballast and delivered to the tube are well below the rated value (the ratio "real to rated power to the tube" is below 60% in 43% of the tested lamps). The resource to this trickery to enlarge the lifetime of the lamps (softening the working conditions of ballast components and reducing the price) seems to be widely extended in the current market, and is a clear symptom of the lack of effective quality assurance procedures. We will further comment on that.

Figure 6 stresses the general cycling resistance improvement associated to the preheating of electrodes. To further disclose this aspect, we performed two different experiments. One of them consisted on adding a preheating of electrodes facility (by adding a rather simple electronic circuit) to an originally "poor" lamp. The corresponding cycling resistance has dramatically improved from less than 2000 cycles to about 100000, i.e., more that 50 times the original value! The other experiment was just the opposite; we eliminated the preheating of electrodes facility of a "very good" lamp, and the cycling resistance fall from more than 30000 cycles to about 1200[40].

However, despite these rather spectacular results, a one-to-one relation between preheating of electrodes and cycling resistance can not be established. Figure 6 shows that poor lamps can be found despite preheating of electrodes[41], and that the opposite, i.e., good lamps without preheating of electrodes also exist. Because of that, the simple verification of the existence of a preheating facility can not be considered as equivalent to good cycling resistance in quality assurance procedures.

Figure 6. Different cycling lifetime distribution of lamps having and not preheating of electrodes.

Figure 7 describes, for lamps not having preheating of electrodes, the relationship between the starting voltage and the cycling resistance. A sort of border around 600 V can be observed, but, again, a one-to-one relationship can not be strictly assured. Hence, the measurement of the starting voltage can not substitute cycling resistance tests in quality assurance procedures. Figure 8 presents the cycling resistance versus the crest factor. It can be observed that both parameters are essentially uncorrelated. In fact, this could be expected because the crest factor seems to be directly associated to the continuous operation of the lamp and only indirectly to the ignition phase. And similar observations and comments apply for the symmetry and the DC component of the current waveform.

Figure 7. Relationship between starting voltage and cycling resistance of the lamps.

Figure 8. Relationship between crest factor and cycling resistance of the lamps.

Figure 9 shows the ratio “real over rated power at the tube”. As already mentioned, it can be observed that underrated lamps have a significant presence in the current market. Obviously, this is an undesirable practice that should be avoided in well-managed PV Rural Electrification programmes.

Figure 9. Percentage of the tube nominal power delivered to the tube.

On the other hand, looking for the establishment of as brief as possible quality assurance tests, we also analysed the possible relationship between cycling resistance and blackening of the tube edges. Two main observations apply. First, despite its high visibility, such blackening do not imply significant luminosity losses of the lamp. To better understand this rather surprising fact, we have measured the brightness of a tube along its revolution axis and found that just the edges correspond to the minimum brightness points. Second, we have observed that all the lamps that have died before 10000 cycles invariably have also shown edge blackening before 5000 cycles, but the corollary is not true, i.e. some lamps showing edge blackening before 5000 still survived after 10000 cycles. In practical terms, this means that edge blackening observation can not generally reduce the time-length of cycling tests, but the last found is still useful when thinking on possible lamp’s quality categorisation. We will come back to that later.

3.2 Resistance to extreme operation conditions

All the lamps have succeeded the high temperature test, which consist on 120 minutes of operation at an ambient temperature of 50^{o}C.

On the other hand, low temperature test consists on verifying if the lamp is able to ignite at 0^{o}C and –15ºC. 34 % of the lamps failed at –15ºC and 9% failed at 0ºC. It is interesting to mention that all of the failed lamps were of low nominal power (<18W) and without preheating electrodes features. It is also worth to note that success on passing this test do not necessarily imply fully proper operation at this extreme condition. In fact, despite safe ignition, we have often observed significant decrease of the lamp luminosity on continuous operation. That suggests the possible convenience of harden the technical standard of reference, by requiring not only safe ignition but also good illumination level on extremely low ambient temperatures. However, that would be very restrictive on the frame of the current state of the art, while the associated benefits would probably be low, because, fortunately, such extremely low temperatures use to be only temporary: just when entering in a empty room, etc.

3.3 Resistance to abnormal operation

Table 3 summarises the test result in relation with lamp protections against abnormal conditions. An outstanding result is that unprotected lamps are largely present in the current market. PV Rural Electrification programmes should be attentive to this fact. It should be outlined, in one hand, that lack of lamp protections can represent a risk of fire at home in case of ballast overheating (we have observed temperatures up to 200^{o}C in some lamp failing protection tests), which is magnified by the usual presence of flammable materials (straw, wood, etc.) in rural homes. In the other hand, the practice of connecting active parts of the ballast to the lamp fixture should also be mentioned because, due to economic reasons, SHS use to avoid grounding, and in ungrounded systems such practice represents an unacceptable risk of injury for persons.

Table 3. Protection test result for the lamps of the market sample.

Figure 10 discloses the tested values of the energy consumption without tube, or with a defective tube. In fact, this situation can often occur and remain unnoticed for the user leading the PV system to blackout, due to the exhaustion of the stored energy at the batteries.

Figure 10. Percencentage of the nominal power consumed by the lamp when working without tube. The dotted line represents the allowed limit by the Universal Technical Standard.

Moreover, we have observed that some lamps protected against open-circuit or short-circuit of ballast outputs, were destroyed when a deteriorated tube that the ballast could not start was installed.

Finally, despite strictly speaking, EMC compatibility is not a protection, we have also included here a simple test consisting on verifying the existence of, both, aerial and through the cables radio frequency interference on a standard commercial receptor. The majority of the tested lamps produce some kind of interference. The real harshness of this problem is very dependent on the particular case; and, unfortunately, easy and general solution for this problem is not available today[42].

3.4 Luminosity

Figure 11 shows the luminous efficiency results in lumens per watt of DC power at the input of the lamp, i.e., at the DC input of the ballast. Observed values are always larger than 25 lumens/W and in 90% of the cases larger that 35 lumens/W, which are the values referred at the here considered norm, and also at another technical standards[20,14,15,16]. However, this apparently comfortable situation is sometimes deceptive, because the real power required by the lamp -and, therefore, the power delivered to the tube- use to be well below the rated values, as figure 9 shows. Only 22% of the tested lamps deliver more than 75% of the rated power to the tube. This leads to illumination levels well below the expected values, despite the acceptable lamp efficiency. Furthermore, this great disparity between real and rated power is an affront to the general confidence on the PV Rural Electrification market, and should be severely persecuted.

Figure 11. Luminous efficiency results in lumens per watt of DC power at the lamp input.

4. Proposed standard modification

Following the previous discussion, some modifications to the lamps content of the "Universal Technical Standard for Solar Home Systems" are here recommended:

Cycling resistance

Due to the lack of one-to-one relationships between tube lifetime and other electrical parameters, we propose to directly consider the lamp cycle resistance as the parameter to be specified and tested. Some steps in this direction has been already given by the World Bank Chinese project, whose specifications[20] require a minimum of 1000 cycles, and by the FISE, whose internal procedure requires a minimum of 10000 cycles for a lamp to be approved. While the first is clearly below the current state of the art (see figure 5), the second tends to be rather restrictive, especially for locally-made products. Our reference standard paid particular attention to include flexibility features that allow it to be adapted to the particular conditions of each country. Following in this line, we propose to consider two different resistance cycling limits: 5000 and 10000 cycles, as compulsory and recommended specification, respectively. This way, the present standard specifications related with lamp life-time, labelled as CL7, CL8, RL3, RL4, and RL5[8], should be substituted by the following norms:

- Compulsory: "*The lamp should resist a minimum of 5000 cycles of switching ON-OFF. Each cycle must consist on 60 second ON and 150 seconds OFF, at the nominal voltage of the lamp*".
- Recommended: "*The lamp should resist a minimum of 10000 cycles of switching ON-OFF. Each cycle must consist on 60 second ON and 150 seconds OFF, at the nominal voltage of the lamp*".

This implies the full elimination in the standard of the technical requirements associated to the continuous functioning of the lamp. However, it should be considered that the main goal of the standard is the quality assurance in real projects. Regarding this subject, we should note that the direct testing of the resistance to continuous functioning is too time consuming for quality assurance purposes (2000 hours, which is the minimum conceivable limit, requires about three months), while the measurement of associated electrical parameters is not conclusive and expensive in terms of the required instrumentation. The experience with the tested lamps (mentioned above) shows that, in the framework of the current state of the art, avoiding testing of continuos functioning do not represents a significant risk of technical quality reduction.

Luminosity

The actual version of the Universal Technical Standard deals with luminosity through the specification labelled CL4, which states that "minimum luminous flux for the total ballast and fluorescent lamp system must be 80% of the nominal value". However, nominal values usually do not refer to the luminous output of the lamp, but to the electrical power at its input. Therefore, in order to better face the today existing practise of underrated lamps, we propose to further clarify the standard text, by substituting such specification by the following:

- Compulsory: "*Minimum DC power at the input of the ballast must be 90 % of the nominal value, in all the range of the operating voltage (-15% to +25% of the nominal value)*".

On the other hand, tested values of the luminous efficiency suggest that the content of the standard can be upgraded but still being not restrictive for locally produced products. We propose to substitute the values of 25, 35 and 50 lum/W, considered at the original standard text as compulsory, recommended and suggested values (specifications labelled as CL6, RL2 and CW2), respectively, by 35, 50 and 60 lum/W.

A rough idea of the meaning of such specifications can be obtained from the following example: a 8 W lamp satisfying the minimum standard requirements (real power equal to 90% of the nominal value, luminous efficiency of 35 lum/W) would provide 252 lum. With the lowest allowed ballast efficiency of 70% allowed in the first version of the Universal Technical Standard for Solar Home Systems, the tube should have a luminous efficiency of 50 lum/W, which is very on the general trend on the current tube technology. Furthermore, such lamp, at a height of 1.4 m – which can be considered as representative of the distance between the surface of a table and the lamp, both placed on the middle of a room – and without any reflector, would provide 13 lux, which is enough for general lighting, according with the recommendation of different references[34,43] . To catch 50 lux, which is the minimum value recommended for the more light demanding activities (reading, task lighting, etc), a reflector should be added or the lamp should be substituted by another of 20 W of nominal power.

It should be noted that the verification of the lamp service quality is related with the testing of luminous efficiency and, therefore, the checking of any other intermediate efficiency is not strictly necessary. Consequently, norm labelled as CL5 (related with ballast efficiency) can be eliminated in order to simplify the application of the norm.

Resistance to extreme operation conditions and to abnormal operation.

In one hand, the deficient behaviour of a great part of the lamps when working in extreme conditions (especially in cold temperatures) suggests us to include this feature as a norm: compulsory in the case of the lamp starting at 0º, and recommended at –15ºC. The correct performance of the lamp at 50ºC has also the character of compulsory.

In the other hand, most of the protections are already included in the cited norm. Only two aspects should be improved. First, the high energy consumption observed in the tested lamps suggests to transform the recommended norm RL1 in compulsory, and second, to add a new recommended norm establishing this limit of consumption in 10% of the nominal power.

5. Conclusions

Procedures to test the adherence of SHSs fluorescent lamps to the so called "Universal Technical Standard for Solar Home Systems" have been developed, and applied to a collection of 42 lamps, directly acquired in the current PV Rural Electrification market. Particular attention has been paid to test simplicity and to instrumentation affordability, in order to make easy the local application of the testing procedures, for example by the organisations which carry out electrification programmes. Tests apply to lamp resistance to normal operation conditions, lamp resistance to extreme operation conditions, lamps resistance to abnormal operation conditions, and lamp luminosity.

Main found from test results is that underrated and unprotected lamps have a significant presence in the current market, so that, quality assurance procedures are fully justified.

In the other hand, there is not a clear one-to-one relationship between lamp lifetime and electrical parameters of immediate measurement, like crest factor, etc. Hence, lamps resistance to normal operation conditions should be directly checked by means of a cycling test. Finally, the content of the selected technical standard has been reviewed, at the light of the previous results, and some modifications have been proposed.

The selected technical standard together with the proposed testing procedures form the basis of a complete quality assurance tool that can be locally applied in common electricity laboratories. Full testing of a lamp requires less than one month, what is very reasonable on the frame of quality assurance programmes.

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